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Effects of nitrogen on accumulation and partitioning of dry matter and nitrogen of vegetables. 1. Brussels sprouts

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Abstract

Brussels sprouts (*Brassica oleracea* L. var *gemmifera* DC) accumulates large amounts of nitrogen and the nitrogen harvest index is low. Detailed information on nitrogen effects on crop development and growth, however, is scarce. Therefore, four experiments were carried out in which treatments consisted of different amounts and different dates of application of nitrogen. Dry matter and nitrogen accumulation of stem, apical bud and groups of leaf blades, petioles and sprouts were measured frequently throughout growth.

Total amounts of accumulated dry matter and nitrogen were affected by amount of nitrogen applied and date of application. Sprout growth started halfway the growing period. The final harvest index for dry matter ranged from 0.10–0.35 and for nitrogen from 0.20–0.55; both were not significantly affected by treatments in most experiments. Nitrate nitrogen concentrations were only high (maximally about 2%) shortly after planting. The total nitrogen concentration of leaf blades and petioles increased with increasing leaf number. This increase resulted from a decreasing nitrogen concentration during the leaf's life. The total nitrogen concentration in sprouts changed little with leaf number.

Keywords: Brussels sprouts, *Brassica oleracea* L. var *gemmifera* DC, nitrogen nutrition, dry matter production, dry matter distribution, nitrogen uptake, nitrogen concentration, nitrogen distribution

Introduction

Brussels sprouts is a biennial plant species with a vegetative phase in the first year and a generative phase in the second year. During vegetative growth, leaves, stem, sprouts and roots develop.

Although some information is available on accumulation and partitioning of fresh and dry matter and nitrogen at harvest in relation to nitrogen nutrition, information on the dynamics of these characteristics during crop growth is scarce. Such information, however, is important for a proper understanding of the nitrogen uptake and for fine-tuning of the nitrogen nutrition to the demand of the crop.

The harvest index of Brussels sprouts is relatively low, compared to other crops. Fisher & Milbourn (1974) examined the partitioning of dry matter as affected by plant density, date of stopping (removal of the apical bud) and leaf removal; Abuzeid & Wilcockson (1989) analysed effects of different plant densities and different sowing dates in three years. In both sets of experiments it was observed that rapid sprout growth did not begin until approximately five months after sowing in May, while about three months later harvest indices between 25 and 40% were observed.

Another scientific question is whether sprout growth results only from photosynthesis occurring during sprout growth or also from relocation of dry matter from the dying leaves to the sprouts, as hypothesized by Verheij (1970). Fisher & Milbourn (1974) concluded from a leaf removal experiment that remobilisation of dry matter from other plant parts is unimportant, confirming results from a ^{14}C tracing experiment, carried out by Wilcockson & Abuzeid (1991).

Neuvel (1990) examined the effects of several amounts and dates of application of fertiliser nitrogen. When sown in April or transplanted in May and with an application of 300 kg ha^{-1} fertiliser nitrogen, the total dry matter production in October was, on average, 14.5 ton ha^{-1} and N uptake about 335 kg ha^{-1}. Maximum sprout yield of about 4.5 ton ha^{-1} dry matter was usually attained at the largest amount of nitrogen applied, i.e. 300 or 375 kg ha^{-1}.

Effects of nitrogen nutrition on leaf development and growth of Brussels sprouts are reported in Biemond *et al.* (1995). A larger total green leaf area, attained with more nitrogen, resulted mainly from larger leaves; the number of leaves increased only slightly. Larger leaves resulted from larger leaf expansion rates. However, amount and timing of nitrogen nutrition also affects plant growth and nitrogen uptake: these aspects are analysed in this paper. The relative partitioning rates of dry matter and nitrogen increase over different plant organs are derived from sequential harvest data.

Materials and methods

A brief description of the design of three glasshouse experiments, described in this paper, suffices here, because details were given by Biemond *et al.* (1995). The fourth experiment was a field experiment and not described before. Experiment 1 was carried out from May 1991 – September 1991, Experiment 2 from November 1991 – April 1992, Experiment 3 from April 1992 – October 1992 and Experiment 4 (the field experiment) from May 1991 – November 1991.

Plant culture – glasshouse

Young Brussels sprouts plants (cv. Icarus SG2004; with six, three and five leaves in Experiments 1, 2 and 3, respectively) were planted in 20–l pots (one plant per pot), containing sand, free from organic matter. The pots were placed in a glasshouse, set to maintain a day (12 h) temperature of 18 °C and a night temperature of 12 °C. On sunny days, the capacity of the cooling system of the glasshouse was insufficient, which resulted in temperatures of 2 or 3 °C above the set temperatures. Natural light

was supplemented with 400 Watt Philips SON-AGRO-T lamps at a density of 0.7 lamps m^{-2}.

Plant culture – field

The field experiment (Experiment 4) was conducted on a clay soil. Plants of the same cultivar and of the same plant size as in Experiment 1 were planted (on 2 May 1991) about 7.5 cm deep in rows, with a row-spacing of 75 cm and a distance between plants within the row of 40 cm, resulting in a plant density of 3.3 plants m^{-2}.

Treatments and experimental design

Each glasshouse experiment had four different treatments (Figure 1), consisting of

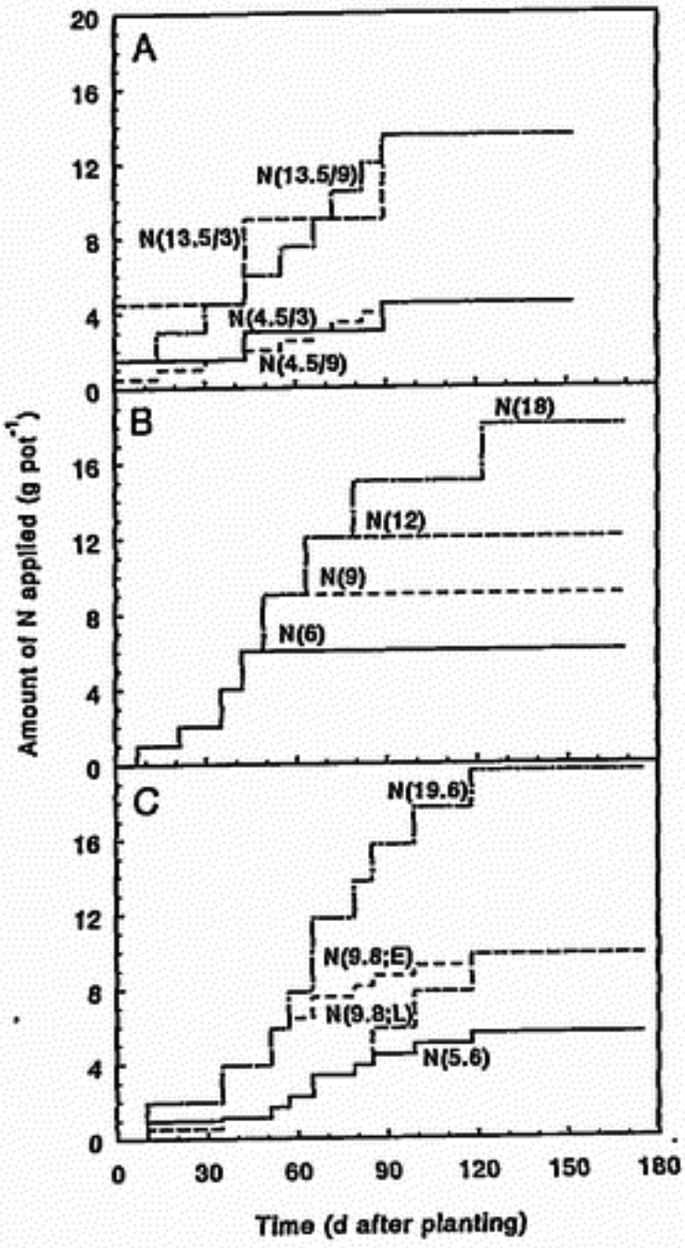

Figure 1. Accumulated amounts (in g per pot) of nitrogen, applied to the different treatments of Experiment 1 (A), Experiment 2 (B) and Experiment 3 (C).

different total amounts and different dates of application of nitrogen. One treatment in each experiment was expected to have no nitrogen stress. Its nitrogen supply was based on previous experience. In Experiment 1 treatments were: N(4.5/3): 4.5 g N per pot, supplied in three splits of 1.5 g; N(4.5/9): 4.5 g N per pot, (nine equal splits); N(13.5/3): 13.5 g N per pot (three equal splits); N(13.5/9): 13.5 g N per pot (nine equal splits). In the statistical analyses, treatments were split into two factors, viz. amount of nitrogen (4.5 vs 13.5 g per pot) and number of applications (three vs nine splits). In Experiment 2, nitrogen was applied in splits of one, two or three g N per pot on such dates that nitrogen shortage could only occur after discontinuing nitrogen supply. Total amounts of nitrogen applied to each treatment were 6 N(6), 9 N(9), 12 N(12) or 18 g N N(18) per pot. In Experiment 3, treatments were: N(5.6): 5.6 g N per pot, with nitrogen limitation throughout the experiment; N(9.8;E(arly)): 9.8 g N per pot, with non-limiting supply in the early stages of growth and limiting supply later; N(9.8;L(ate)): 9.8 g N per pot, with limiting supply in the early stages of growth and non-limiting supply later; N(19.6): 19.6 g N per pot; non-limiting nitrogen supply throughout the experiment. Other nutrients were supplied in equal amounts to all treatments. Nitrogen supply for treatments with nitrogen stress was based on a comparison of actual growth (which was regularly measured at destructive harvests) with growth and nitrogen uptake in Experiments 1, 2 and 4.

The glasshouse experiments were laid out in a randomised complete block design with four blocks, with each pot regarded as one experimental unit. At the start of the experiments, each block consisted of 28 (Experiment 1) or 32 (Experiments 2 and 3) pots (see *Sampling and plant analyses*).

Experiment 4 had three treatments: N(0): no application of fertiliser nitrogen; N(120+80): 200 kg N per ha, applied in two splits (120 kg ha^{-1} at 1 and 80 at 95 days after planting (DAP)); N(200/5): 200 kg N per ha, applied in five equal splits (at 1, 32, 61, 81 and 95 DAP). A week before planting 168 kg ha^{-1} mineral N was available in the soil layer 0–90 cm. This experiment was laid out in a split-plot design with four blocks; nitrogen treatment was main factor and harvest date (see *Sampling and plant analyses*) split factor. Statistical analyses of each experiment were separate for each harvest, since we were interested in differences among treatments and not specifically among harvests. The significance of differences is assessed with an LSD-test (P=0.05), after an analysis of variance.

Sampling and plant analyses

Destructive analyses of plants were carried out several times: in Experiment 1 on six occasions between 29 and 152 DAP (days after planting), in Experiment 2 on nine occasions between 28 and 169 DAP, in Experiment 3 on eight occasions between 29 and 175 DAP and in Experiment 4 on three occasions (68, 126 and 186 DAP). In Experiments 1–3 one plant per treatment was used from each block on each sampling date; in Experiment 4 on each sampling date four plants per treatment were used from each block.

The measurements in Experiments 1–3 included leaf area, and fresh and dry weights of leaf blades, petioles, sprouts, stem and top (= cluster of young leaves, shorter than 5 cm, at the top of the stem). In the growth analysis, leaf blades, petioles

and sprouts from three (Experiment 1) or five (Experiments 2 and 3) nodes were pooled. Dead leaf blades and petioles were collected. The measurements in Experiment 4 included leaf area, and fresh and dry weights of all leaf blades, all petioles, all sprouts and stem. Dead leaves and petioles were not collected in this experiment. With the term 'leaf number' always the leaf insertion number is meant; otherwise the term 'number of leaves' is used.

Dried samples were ground. To reduce the number of samples for chemical analysis, the samples from the replicates of Experiments 1–3 were pooled and mixed thoroughly. One subsample from this pooled sample was subsequently analysed for total nitrogen and nitrate (Biemond & Vos, 1992). However, at the final harvest the replicates were not pooled; leaf blades, petioles and sprouts from all nodes of one plant were pooled after drying and subsequently analysed for total nitrogen and nitrate (Biemond & Vos, 1992). All samples of Experiment 4 were analysed, the replicates were never pooled.

In this paper organic nitrogen is the difference between the total nitrogen concentration and the nitrogen present as nitrate.

Results

Accumulation of dry matter and nitrogen

Figure 2 shows the relations between total dry matter production, total nitrogen uptake, dry matter in sprouts, and nitrogen in sprouts at the final harvest of each experiment; each datum point represents one of the treatments. Especially the relation between total dry matter production and total nitrogen uptake differed considerably between experiments. The relations depicted in the other three quadrants were fairly conservative, as data from most experiments and treatments fell on a common line, except that the field experiment deviated somewhat from the general pattern, because shed dead leaf blades and petioles were not included. In most cases the total dry matter production or sprout nitrogen uptake still increased with increasing sprout dry matter production or total nitrogen uptake. Linear regression lines would practically pass through the origin. This means that harvest indices for dry matter and nitrogen and total and sprout nitrogen concentrations were fairly constant over ranges of dry matter production and nitrogen uptake.

Partitioning of dry matter to different plant organs

In all experiments sprout growth started between 70 and 100 DAP. In Experiments 1 and 3 sprout growth started three weeks earlier in the two treatments with a large supply of nitrogen shortly after planting, compared to the two treatments with a low initial rate of nitrogen supply. The final harvest indices are shown in Table 1. They were higher in Experiment 4, compared to the glasshouse experiments, because shed dead leaf blades and petioles were not included in total dry matter. When these plant parts were excluded from the total dry matter in Experiment 1 (which was carried

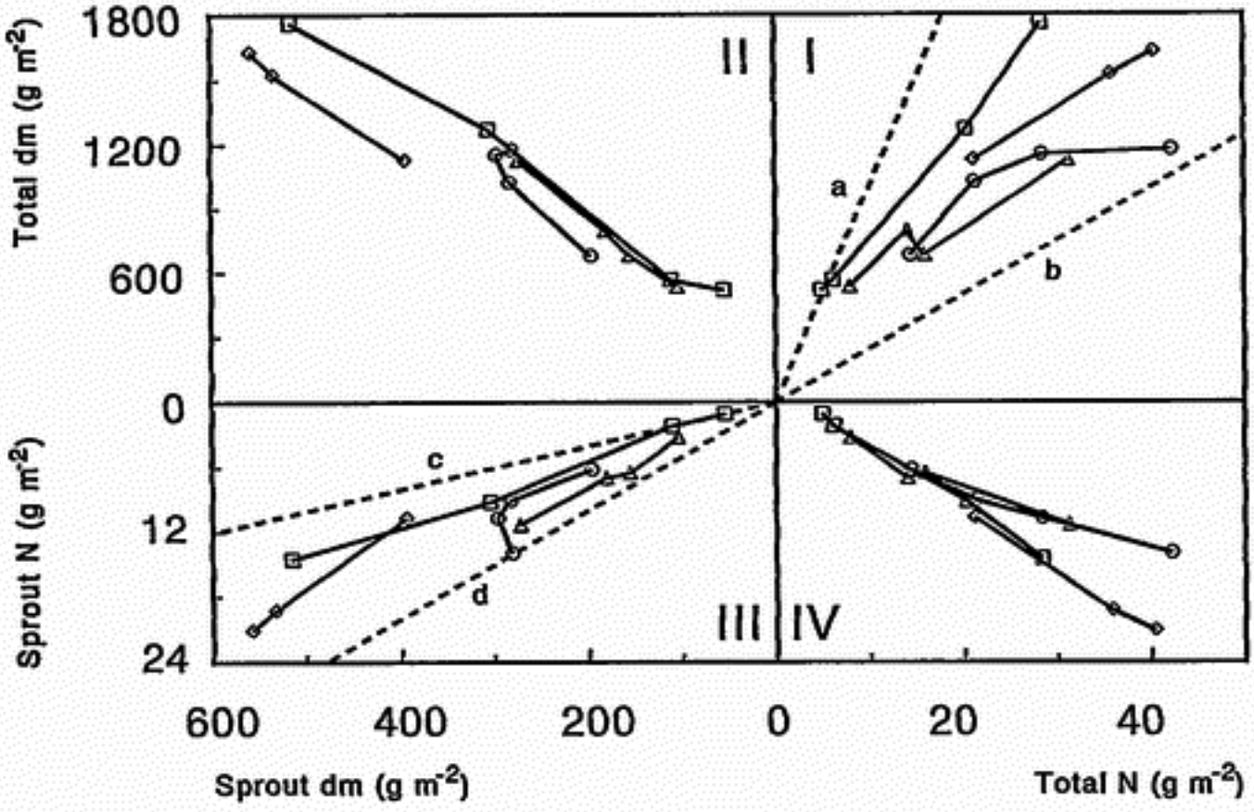

Figure 2. Relations between total dry matter production (Total dm), sprout dry matter production (Sprout dm), total nitrogen uptake (Total N) and sprout nitrogen uptake (Sprout N) at the final harvest of each experiment. All variables are in g m^{-2}. The dotted lines in quadrants I and III represent 1 ('a'), 4 ('b'), 2 ('c') and 5 ('d') % nitrogen in the total or sprout dry matter. (□) Experiment 1; (○) Experiment 2; (△) Experiment 3; (◇) Experiment 4.

out in the same year and period as Experiment 4, with the same cultivar), the harvest index was on average 0.32, stressing the importance of leaf shedding. Except in Experiment 1, amount or date of application of nitrogen did not significantly affect the harvest indices.

Figure 3 shows the changes with time in the relative partitioning rates of dry matter increase to the stem, the leaf blades (including dead ones and top of the plant), petioles (including dead ones) and sprouts. The relative partitioning rates are calculated as the increase in dry matter of a particular plant part over a period of time between harvests, divided by the total increase of dry matter in the same period. The trends as shown for Experiment 3 in Figure 3 were similar in Experiments 1 and 2; the data of Experiment 4 are not comparable, because dead leaf blades and petioles were not sampled in this experiment. After a slow increase for a longer period, the relative partitioning rate to the stem usually decreased at the end of each experiment. The relative partitioning rate to the leaf blades decreased until the penultimate harvest. The relative partitioning rate to the petioles increased until about 50 DAP and usually decreased thereafter. A negative value for the relative partitioning rate to leaf blades or petioles resulted from a decreasing amount of dry matter in these plant parts: reallocation (to the sprouts) probably has occurred there. The relative partitioning rate to the sprouts increased after sprout initiation in nearly all cases until the

Table 1. The harvest index for dry matter and for nitrogen at 152 DAP for Experiment 1, at 169 DAP for Experiment 2, at 175 DAP for Experiment 3 and at 186 DAP for Experiment 4. In Experiment 4 dead leaf blades and petioles were not included in total dry matter and total nitrogen uptake. LSD values are included where factors had more than two levels.

Harvest index for dry matter

Experiment 1[1]		Experiment 2[2]		Experiment 3[2]		Experiment 4[2]	
N(4.5/3)	0.195	N(6)	0.279	N(5.6)	0.194	N(0)	0.348
N(4.5/9)	0.100	N(9)	0.272	N(9.8;E)	0.227	N(120+80)	0.349
N(13.5/3)	0.291	N(12)	0.248	N(9.8;L)	0.232	N(200/5)	0.341
N(13.5/9)	0.232	N(18)	0.236	N(19.6)	0.223		
		LSD	0.057	LSD	0.075	LSD	0.031

Harvest index for nitrogen

Experiment 1[1]		Experiment 2[2]		Experiment 3[2]		Experiment 4[2]	
N(4.5/3)	0.352	N(6)	0.430	N(5.6)	0.404	N(0)	0.504
N(4.5/9)	0.216	N(9)	0.426	N(9.8;E)	0.498	N(120+80)	0.538
N(13.5/3)	0.510	N(12)	0.376	N(9.8;L)	0.412	N(200/5)	0.516
N(13.5/9)	0.445	N(18)	0.329	N(19.6)	0.359		
		LSD	0.096	LSD	0.141	LSD	0.034

[1] applying 13.5 instead of 4.5 g N per pot and in three times instead of nine resulted in significantly higher harvest indices for dry matter and for nitrogen.
[2] in Experiments 2, 3 and 4, analysis of variance showed treatment differences were not significant.

penultimate harvest. In Experiments 1 and 2 the relative partitioning rate to sprouts was never above 1.0. The only effect of nitrogen treatments on the pattern of distribution of dry matter was the delayed sprout growth for treatments with a low availability of nitrogen shortly after planting.

Partitioning of nitrogen to different plant organs

The harvest index for nitrogen was always higher than the harvest index for dry matter, because the nitrogen concentration in sprouts was higher than that of the whole plant. Final values of the harvest index for nitrogen are shown in Table 1. Although significant effects were only observed in Experiment 1, higher amounts of nitrogen in Experiment 2 resulted in slightly lower harvest indices for nitrogen. The harvest indices for dry matter in N(9.8;E) (the treatment with the early nitrogen application) and N(9.8;L) (the treatment with the late nitrogen application) of Experiment 3 were similar, but the harvest index for nitrogen was 25% higher for N(9.8;E). When dead leaf blades and petioles in Experiment 1 were excluded from the calculation of the harvest index for nitrogen, it was on average 0.44; Experiment 4 had a value of on average 0.52, also with excluding dead leaf blades and petioles.

The change with time in the relative partitioning rate of nitrogen increase to the distinguished component plant parts is shown in Figure 4 for Experiment 3. The

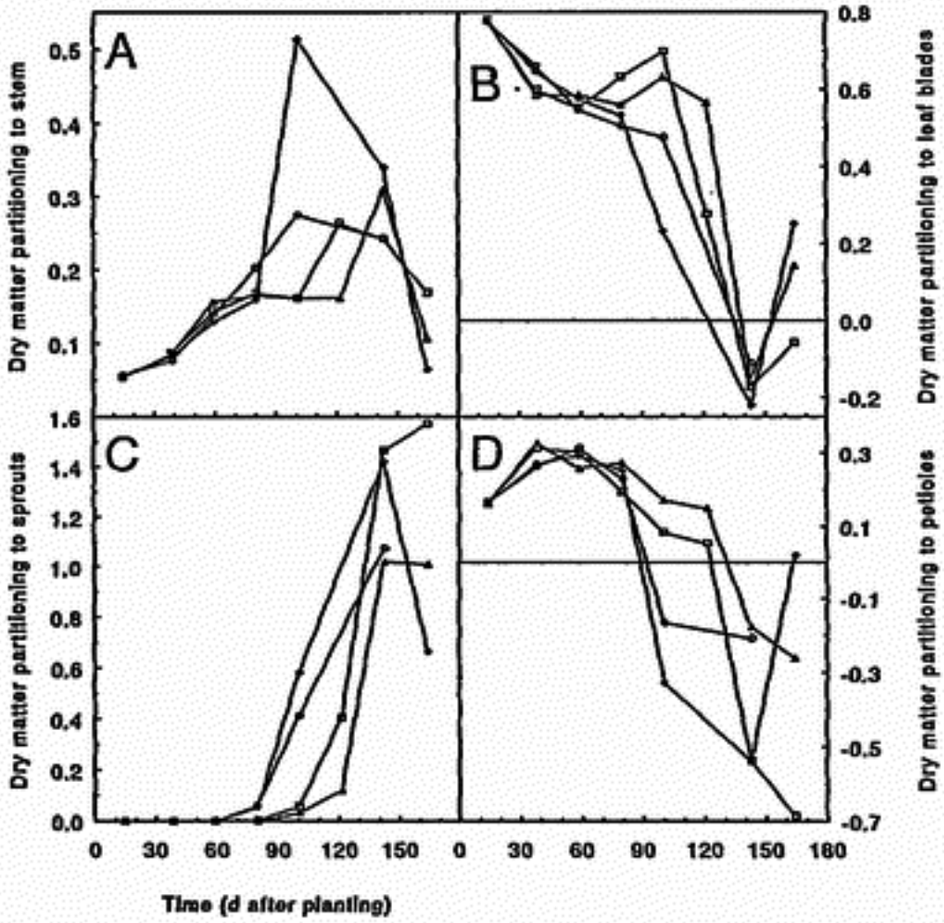

Figure 3. Changes with time in the relative partitioning rates of dry matter increase to the stem (A), the leaf blades (including dead ones and top of the plant; B), the sprouts (C) and the petioles (including dead ones; D) of Experiment 3. Mind differences in scales of y-axes. (□) N(5.6); (○) N(9.8;E); (△) N(9.8;L); (◇) N(19.6).

overall pattern is similar to the one observed for the relative dry matter partitioning (Figure 3). The treatments of the different glasshouse experiments all showed similar patterns, except that there was no decrease at the end of Experiment 2 in the relative partitioning rate of nitrogen increase to the stem. Variation in the proportion of additional N allocated to the stem suggests that the pool of N in stems acts as a buffer to store N taken up in excess of current requirements. The relative partitioning rate to leaf blades decreased during the whole growing period and was negative at the end, as a result of reallocation of nitrogen, apparently to sprouts. The relative partitioning rate to petioles increased slightly during the first half of the growing periods and decreased during the second part. High harvest indices for nitrogen (Table 1) were generally associated with high relative partitioning rates to sprouts and low relative partitioning rates to leaf blades and petioles at the end of the growing periods. The treatments with the lowest amount of nitrogen in each experiment did not always comply with this rule, especially not N(6) of Experiment 2: the final harvest index for nitrogen was high, but a relatively small fraction of nitrogen was reallocated from the leaf blades and the petioles to the sprouts.

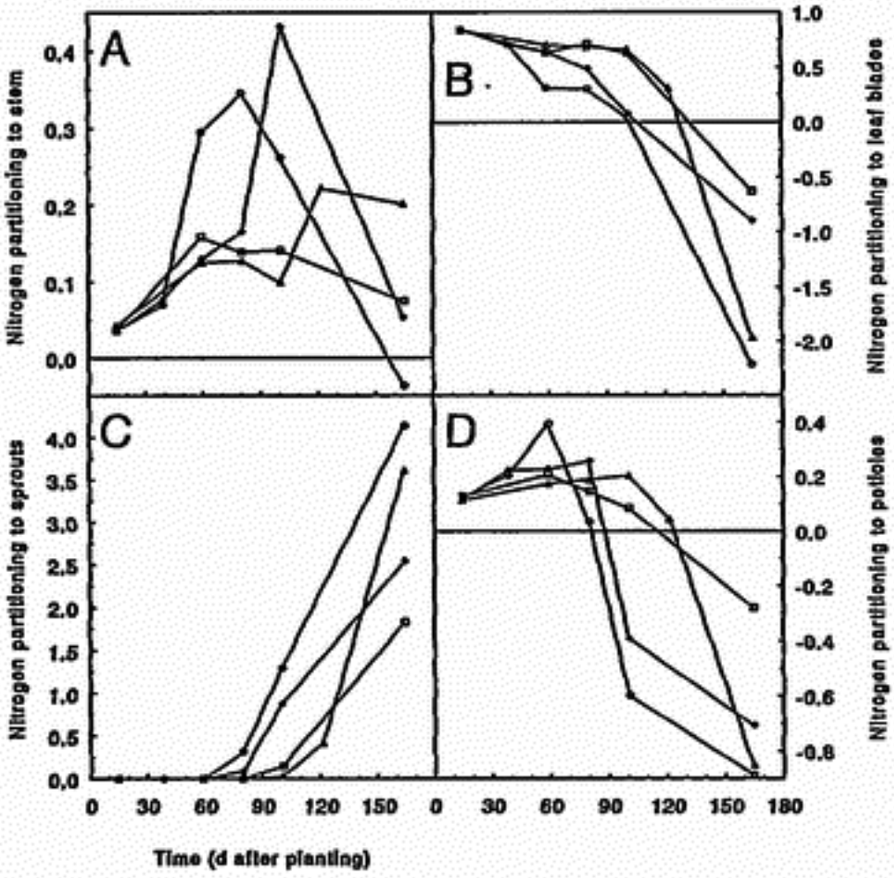

Figure 4. Changes with time in the relative partitioning rates of nitrogen increase to the stem (A), the leaf blades (including dead ones and top of the plant; B), the sprouts (C) and the petioles (including dead ones; D) of Experiment 3. Mind differences in scales of y-axes. (□) N(5.6); (○) N(9.8;E); (△) N(9.8;L); (◇) N(19.6).

Concentration of nitrogen and nitrate

The average nitrogen concentration over all above-ground plant parts was lower at planting time than at the first intermediate harvest in all experiments, except in Experiment 2. Usually this concentration subsequently decreased continuously until the end of each experiment (Figure 5). This general pattern was affected by changes in the nitrogen availability; in this way the average nitrogen concentration could increase, as happened to N(9.8;L) of Experiment 3 after the addition of extra nitrogen.

The nitrate nitrogen concentration over all above-ground plant parts (data not shown) was below 0.1% at most harvests, except for Experiment 2 and in the other experiments shortly after planting. In Experiments 1, 3 and 4 concentrations between 0.7 and 2.0% were observed at the first intermediate harvests for treatments which received a high amount of nitrogen shortly after planting, but this nitrate had disappeared after 50 DAP. The nitrate nitrogen concentration in Experiment 2 fluctuated around 1.75% until 100 DAP, whereafter it decreased for all treatments; final values were below 0.25%.

The nitrate nitrogen concentration in leaf blades and petioles had no clear relation with their total nitrogen concentration. Figure 6 shows a positive relation between

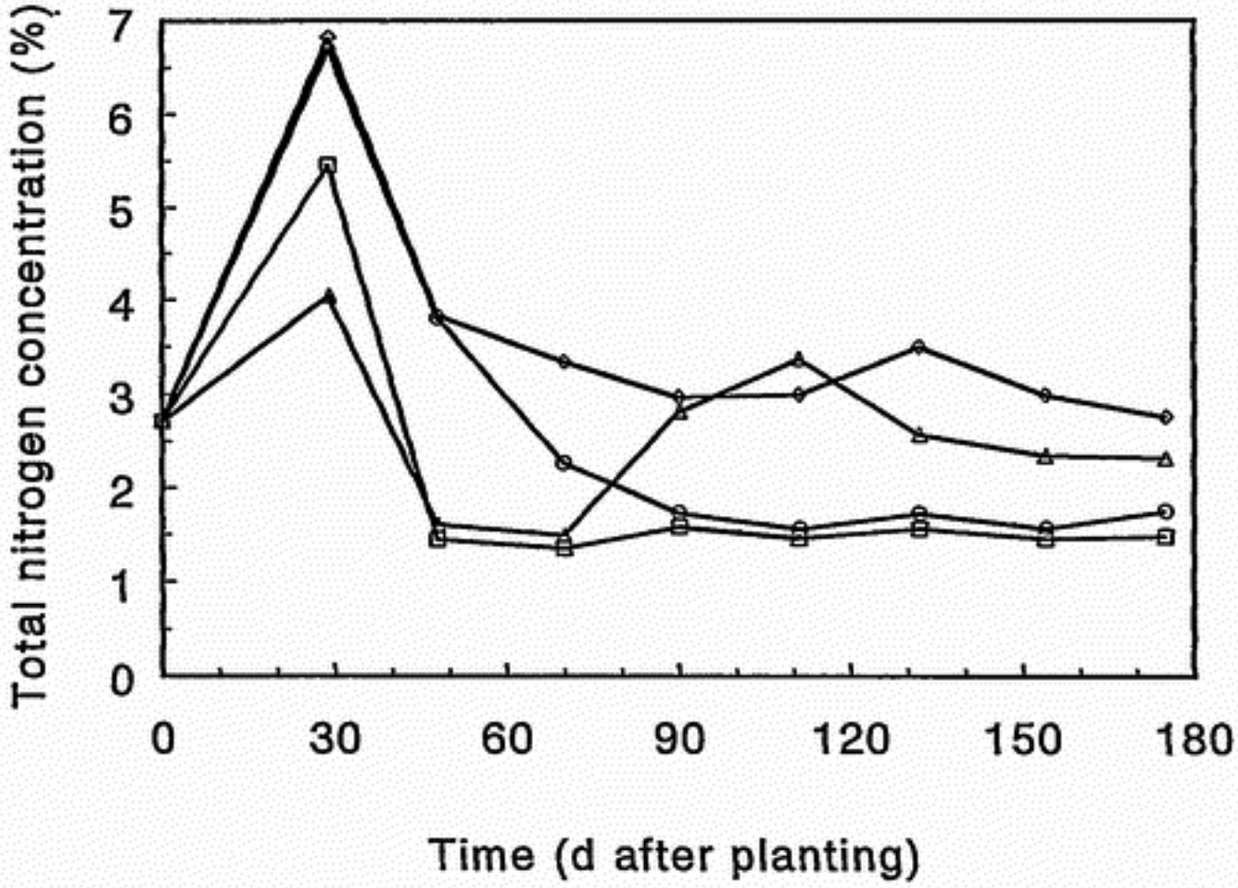

Figure 5. Changes with time in the concentration of total nitrogen in the dry matter of all above-ground plant parts for Experiment 3. (□) N(5.6); (○) N(9.8;E); (△) N(9.8;L); (◇) N(19.6).

the nitrate nitrogen and the total nitrogen concentration of the stems for data from all treatments at all harvests of all experiments. A linear regression for all data from Experiments 1, 3 and 4 where the nitrate nitrogen concentration was above 0.1% was carried out. The data from Experiment 2 were excluded, because the relation seemed to be different for this experiment, which was carried out in winter. The regression equation (n=17; r^2=0.80) revealed that nitrate started to accumulate at a rate of 0.57% nitrate nitrogen per 1.00% total nitrogen above 2.07% total nitrogen. This equation represents the upper limit of possible nitrate nitrogen concentrations.

Concentration of nitrogen and nitrate in plant organs of different nodes

The total nitrogen concentrations of different groups of leaf blades, petioles and sprouts are shown in Figure 7 for Experiment 3 at 90 and 154 DAP. The lowest concentrations for green leaf blades (Experiment 3: about 1.0%) or petioles (Experiment 3: about 0.5%) were similar at all harvests of a certain experiment, but the gradient in total nitrogen concentration with leaf number declined as the canopy aged. Petioles always had lower concentrations than the corresponding leaf blades. The total nitrogen concentration of a certain group of leaf blades or petioles decreased with time, but it was more or less constant for sprouts. The trends as observed in Figure 7 were similar in all three glasshouse experiments. In Experiment 1 the differences be-

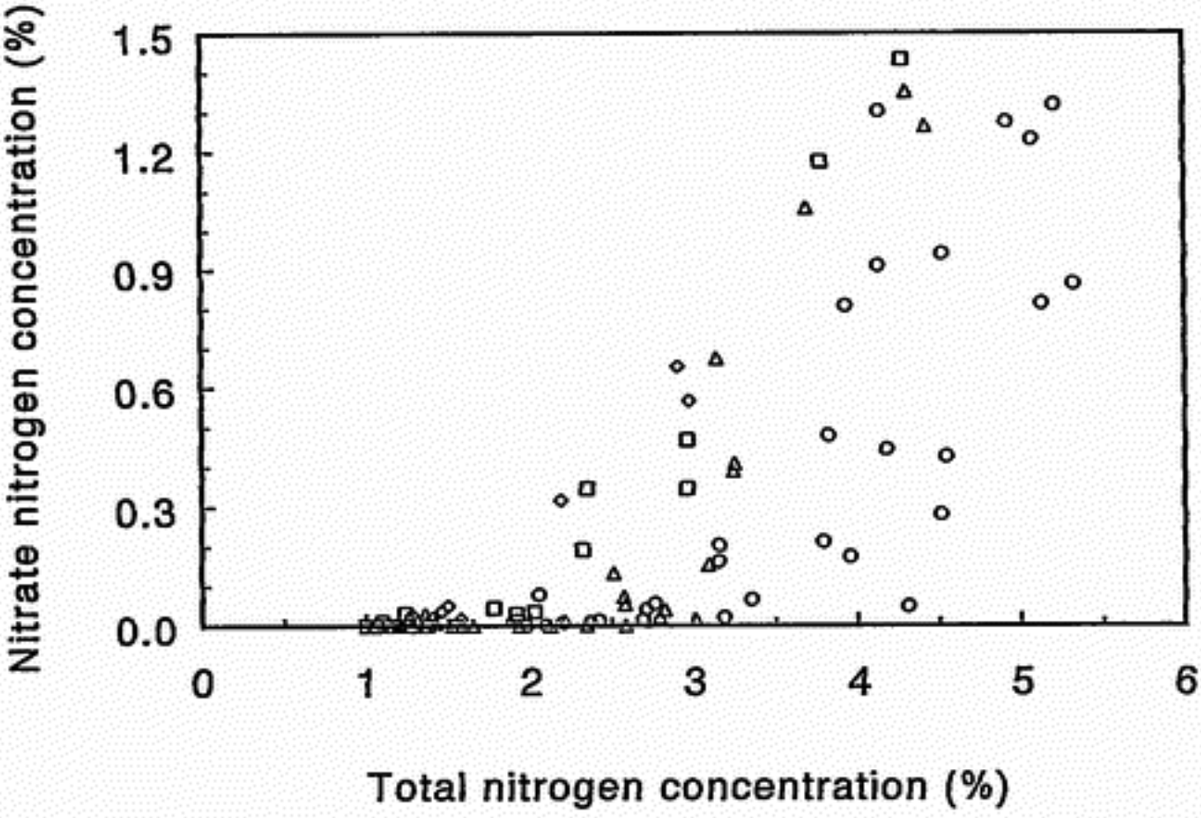

Figure 6. The concentrations of nitrate nitrogen (i.e. N present as nitrate) in the dry matter of stems plotted against the concentrations of total nitrogen in the dry matter. Data from all harvests from all treatments from all experiments. (□) Experiment 1; (○) Experiment 2; (△) Experiment 3; (◇) Experiment 4.

tween treatments were very small at all harvests. In Experiment 2 differences between treatments developed during the growing season, treatments with a larger amount of fertiliser nitrogen having higher concentrations. This sometimes resulted in differences between treatments in total nitrogen concentration of the same leaf blade numbers of more than 4% (nitrate nitrogen was negligible). In N(18) of Experiment 2 the increase with leaf number was very slow at 154 and 169 DAP. This was observed over a longer period in N(19.6) of Experiment 3 (see Figure 7): the increase in total nitrogen concentration with leaf number disappeared with increasing plant age, while this increase stayed with the other three treatments.

In Experiments 1 and 3 differences in total nitrogen concentration between different groups of sprouts were small (see Figure 7), mainly because lower sprout numbers had much higher concentrations than lower leaf numbers. In Experiment 2 there was a decrease in total nitrogen concentration with increasing sprout number, especially at the first harvests where sprouts were present. At 169 DAP the concentrations were nearly equal for all sprout numbers.

In Experiments 1 and 3 the highest nitrate nitrogen concentrations, found in leaf blades, were about 2%. These concentrations decreased with increasing leaf number. In petioles maximum concentrations of about 4% were found, which also decreased with increasing leaf number. The period in which nitrate was present in important concentrations in these two experiments, was until about 50 DAP. In Experiment 2 nitrate was present over a longer period, until about 125 DAP. Maximum concentra-

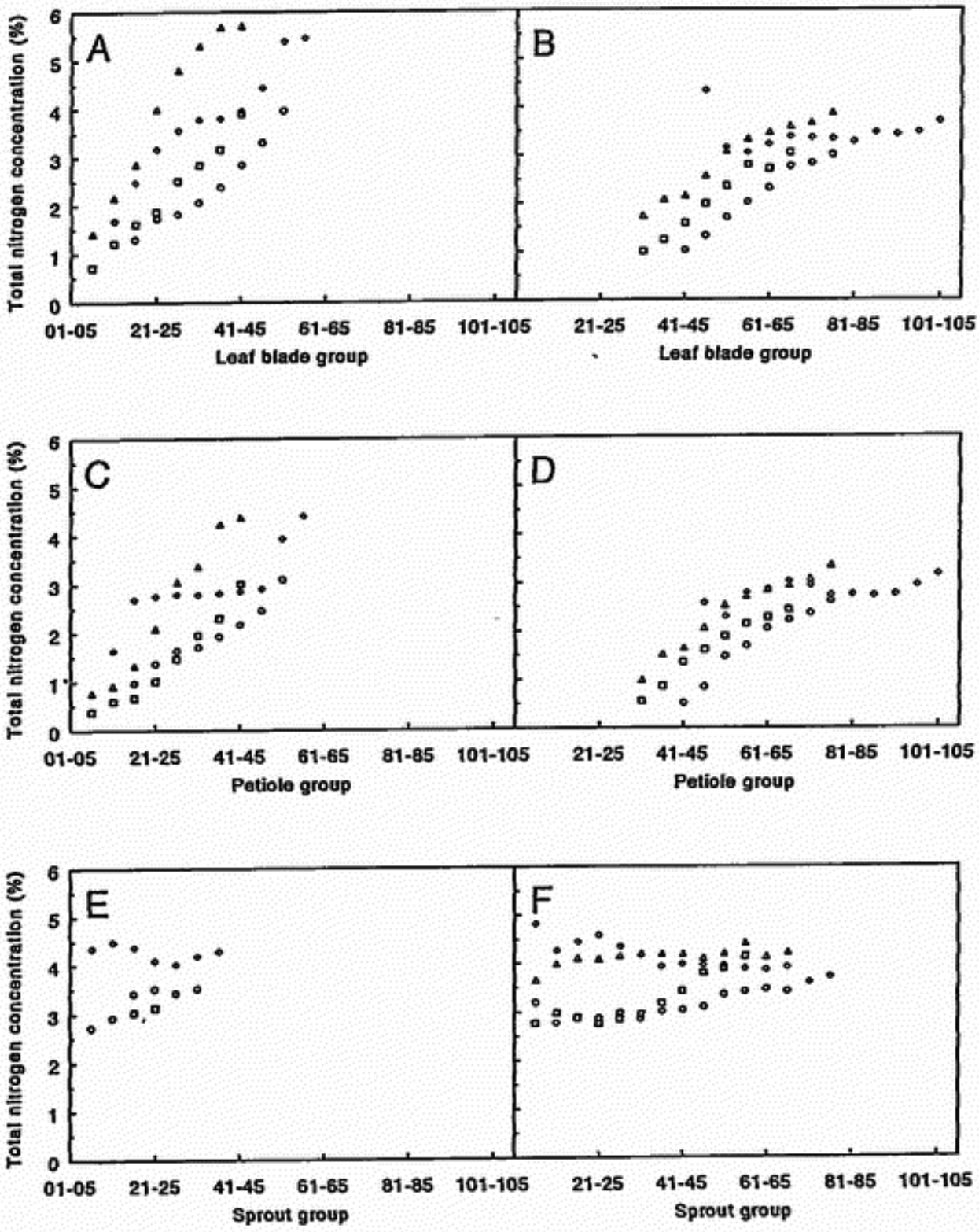

Figure 7. The concentration of total nitrogen in the dry matter of the different groups of leaf blades (A and B), petioles (C and D) and sprouts (E and F) for Experiment 3 at 90 (A, C and E) and 154 DAP (B, D and F). (□) N(5.6); (○) N(9.8;E); (△) N(9.8;L); (◇) N(19.6).

tions, found in leaf blades, were about 3% and about 4% in petioles. They decreased with increasing leaf number. The nitrate nitrogen concentration in sprouts was always negligible in all experiments.

Discussion

Both amount of nitrogen applied and timing of the nitrogen fertilisation affected the accumulation and partitioning of dry matter and nitrogen of Brussels sprouts in various ways. In the tested ranges of applied amounts of fertiliser nitrogen, there were always positive effects on dry matter production.

A larger amount of nitrogen led to an earlier start of sprout growth, but effects on the harvest index for dry matter were insignificant (except in Experiment 1), confirming results of J.J. Neuvel (pers. comm.). Abuzeid & Wilcockson (1989) found a final harvest index between 25 and 40% (including easy recoverable roots and dead leaves in total dry matter) in three field experiments with Brussels sprouts, the variation being the result of different sowing dates. Fisher & Milbourn (1974) found similar values with varying plant densities, dates of stopping and several cultivars, excluding dead leaves and roots from total dry matter.

A higher harvest index for nitrogen compared to the harvest index for dry matter was also observed by J.J. Neuvel (pers. comm.) in experiments with various cultivars.

Usually the total nitrogen concentration of a crop decreases with increasing plant mass (Greenwood *et al.*, 1986, 1990). In Experiments 1, 3 and 4, this concentration was relatively low at planting time and increased until the first intermediate harvest. This low concentration of transplants, also observed by J.J. Neuvel (pers. comm.), was apparently due to the poor nutritional status before planting (= 0 DAP), which was not the case for the transplants of Experiment 2. The total nitrogen concentration in Experiment 2 was high over a long period, (in contrast with Experiments 1, 3 and 4, where it decreased quickly after the first intermediate harvest) as a result of the low light intensity during this winter period. This was also the cause of the prolonged high nitrate nitrogen concentrations in Experiment 2: a low light intensity results in a higher nitrate concentration (Van Diest, 1986).

An increasing total nitrogen concentration of leaves with increasing height in the plant is often found. It is usually explained as an effect of leaf age and as being more efficient for the plant, because the leaves with the higher nitrogen concentration are in the upper canopy layers. There they receive more light, which can be utilised more effectively by leaves with a high than by leaves with a low nitrogen concentration (Hirose & Werger, 1987). An increasing total nitrogen concentration with leaf number was, however, not found in all cases. Sometimes even lower leaf numbers had high nitrogen concentrations (N(19.6) in Figure 7B). A large part of this nitrogen was apparently luxury consumption (this phenomenon occurred only in treatments which received a large amount of nitrogen), but still the question arises, why this nitrogen was present as organic nitrogen and hardly as nitrate nitrogen. The higher total nitrogen concentration in lower sprout numbers, compared to lower leaf numbers, was usually no luxury consumption, because it was observed for all treatments.

Whenever nitrate was present, its concentration was highest in the lowest (= oldest) leaf blades or petioles. Darwinkel (1975) observed for crops as turnip and rape the highest nitrate concentration in the oldest leaves and explained this as a result of the low nitrate reductase activity in these leaves.

The results from our experiments show that it is important for the production of a Brussels sprouts crop that, especially at the beginning of the growing season, sufficient nitrogen for unrestricted growth is available. When this is not the case, the sprout growth is delayed, which is apparently the cause of a lower final harvest index for dry matter (which means the absolute amount of dry matter in sprouts is lower because the total amount of dry matter was also lower). The high final harvest index for nitrogen for treatments with sufficient nitrogen for unrestricted growth at the beginning of the growing season, but not at the end, is interesting from an environmental point of view. With a high harvest index for nitrogen, a relatively low amount of nitrogen is left on the field in crop residues at harvest. This means less nitrogen can leach after mineralization of the crop residues.

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